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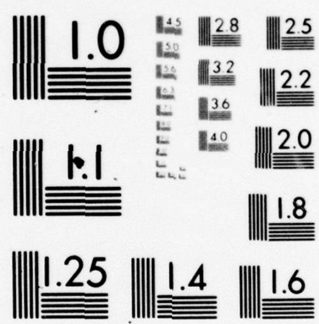

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DISTRIBUTION AND CLASSIFICATION OF OCEAN FRONTS

by

R. E. Cheney
D. E. Winfrey

U. S. NAVAL OCEANOGRAPHIC OFFICE
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Locations and acoustic significance of many fronts (water mass boundaries) are classified as strong, moderate and weak. The characteristics of the Gulf Stream Front, the Slope Front and the Sargasso Sea Front are described.

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ABSTRACT

Ocean fronts occur at boundaries between water masses with differing characteristics. They are narrow regions of rapidly changing properties such as temperature, salinity, and sound velocity and are often accompanied by changes in mixed layer and thermocline depth. Fronts can therefore be of vital importance in understanding both short and long range underwater sound transmission. This report provides locations of many of the world's fronts and classifies them according to their acoustic significance. Characteristics of three fronts in the western North Atlantic are presented; the Gulf Stream provides an example of a strong front, the Slope Front is moderate, and the Sargasso Sea Front is representative of a weak front.

DISTRIBUTION AND CLASSIFICATION OF OCEAN FRONTS

INTRODUCTION

The development of improved ASW/USW tactics depends to a great extent on a more thorough understanding of the ocean environment. Knowledge of local acoustic conditions can provide an effective tool for both detection and evasion. One part of the environmental problem which can be of significant importance concerns ocean fronts. Acoustic studies and experiments performed in the Gulf Stream, the strongest of the Atlantic Ocean fronts, have shown dramatic effects on both short and long range propagation (Laevastu, et al., 1971, James, 1972, Gemmill, 1974, Levenson and Doblar, 1976, Khedouri and Gaborski, 1976). Depending on a submarine's position relative to such a front he may successfully avoid detection or transmit sound for hundreds of miles.

Fronts are found in all the world's oceans, although only a few are as intense as the Gulf Stream. Their characteristics are quite variable and some fronts are purely seasonal. Each individual front may thus have a different acoustic effect with the result that certain ocean fronts are tactically more important than others. This preliminary report provides general locations of many of the world's fronts and classifies them according to their acoustic significance. Selected frontal systems will be discussed in greater detail in future reports.

DEFINITION OF AN OCEAN FRONT

The world's oceans are not homogeneous but are separated into distinct water masses, each with its own temperature and salinity relationship. The transition from one water mass to the next usually occurs quite abruptly across a narrow zone known as a front. Temperature and salinity may change across a major front by as much as 18°F and 2 °/₀₀ in the space of 20 nmi. Corresponding changes in the vertical structure alter the level of the thermocline and deep sound channel. An ocean front thus represents a region of significant variation in acoustic characteristics.

Somewhat weaker fronts are also found within individual water masses. These are often formed by opposed wind systems, such as the trade winds and the prevailing westerlies in the Atlantic, which create a convergence of surface waters with slightly different temperatures. Large scale eddies represent still another class of front, since they are separate entities with their own closed circulation. Gulf Stream eddies, for example, are typically 50-100 nmi in diameter, last up to 2 years, and when first formed have as significant an effect on acoustics as the Gulf Stream itself. Approximately 5 eddies form to each side of the Gulf Stream during a year and 15 may exist at any one time (Cheney and Richardson, 1975).

Because there are many different types of fronts, a variety of criteria have been used to define them in classical oceanographic terms. According to Cromwell and Reid (1965) an ocean

front is "a band at the sea surface across which the density changes abruptly". This would seem to be expressed in sufficiently broad terms for general use, however, Levine and White (1970) observed fronts in the Mediterranean which were strong at the level of the thermocline but were not detectable at the surface. Voorhis and Hersey (1964) required a minimum horizontal temperature gradient of about 3°F per 10 nmi to qualify as a front, but this does not take into account the existence of salinity fronts which have no thermal gradient. Other fronts such as the Maltese Front near Sicily have a very small temperature gradient associated with them but represent a significant change in layer depth.

A more useful definition for the purposes of naval operations can be simply stated: A front is any discontinuity in the ocean which significantly alters the pattern of sound transmission and propagation loss. Thus a rapid change in depth of the sound channel, a difference in sonic layer depth, or a temperature inversion would denote the presence of a front.

ACOUSTIC EFFECT OF FRONTS

An ocean front represent a boundary between two regimes with many different characteristics. In addition to the obvious difference in temperature and salinity, there may exist differences in biological population, wave height, current speed and direction, water color, light transmission, and chemical quantities such as nutrients and dissolved oxygen. In terms of acoustics the following changes can be of significant importance as a front is crossed:

1) Surface sound velocity can change by as much as 100 ft s^{-1}. Although this is due to the combined effect of changing temperature and salinity, temperature is usually the dominant factor.

2) Differences in sonic layer depth (SLD) on the order of 1000 ft can exist on opposite sides of a front during certain seasons.

3) A change in in-layer and below-layer gradient usually accompanies a change in surface sound velocity and SLD.

4) Depth of the deep sound channel (DSC) can change by 2500 ft when crossing from one water mass to the next.

5) Increased biological activity generally found along a front will increase reverberation and ambient noise.

6) Sea-air interaction along a frontal zone can cause a dramatic change in sea state and thus increase ambient noise levels.

7) Bending of sound rays as they pass through a front at an oblique angle can cause bearing errors.

It is clear that any one of these effects can have a significant impact on ASW operations. Together they determine the mode and range of sound propagation and thus control the effectiveness of both short and long range acoustic systems. The short range problem as applied to ASW is dealt with in more detail by James (1972).

WORLD-WIDE FRONTAL DISTRIBUTION

In order to provide an summary of known positions and characteristics of ocean fronts, a survey of available literature

was conducted. Mean positions of reported fronts are shown in Fig. 1. Numbers correspond to the generally accepted names in Appendix A. Each front was categorized as either strong, moderate, or weak by comparing representative values for each of the following three parameters: maximum change in sound velocity across the front, change in sonic layer depth, depth to which the front extends, and persistence. Each front's overall rating was then determined according to the criteria in Table 1.

Table 1
Criteria* for rating the relative
strength of ocean fronts

	Maximum change in sound velocity (ft s^{-1})	Change in SLD (ft)	Depth (ft)	Persistence
Strong	>100	>500	>3000	year-round
Moderate	50-100	100-500	300-3000	year-round
Weak	< 50	<100	<300	selected seasons only

It should be emphasized that Fig. 1 presents only mean positions of the various fronts. Fronts exhibit a great deal of seasonal variability and at any one time may be located as much as 100 nmi to either side of this mean. An example is provided

*Because of fronts' inherent variability, characteristics of any one front may not always fall within one category; these criteria are for general classification only.

in Fig. 2 which shows consecutive positions of the path of the Gulf Stream over the period of a year. Extensive meandering, a common characteristic of virtually all fronts, forms an envelope of positions inside which the Gulf Stream is always found.

FRONTS IN THE WESTERN NORTH ATLANTIC

Examples of fronts in each of three categories can be found in the North Atlantic; the Gulf Stream is a strong front, the Slope Front is moderate, and the Sargasso Sea Front is weak. Fig. 3 shows an enlarged view of this region. A representative population of warm and cold eddies (Cheney, 1976) has been included since they qualify as strong fronts when first formed. As they decay they may eventually deteriorate into the moderate category (Cheney and Richardson, 1976). Some of the acoustic effects of eddies are discussed by Vastano and Owens (1973) and Gemmill and Khedouri (1974).

a) The Gulf Stream dominates circulation in the western North Atlantic. It has its origin in the Gulf of Mexico where it is known as the Loop Current, flows through the Straits of Florida, and hugs the coast up to Cape Hatteras. It then leaves the coast and flows eastward across the Atlantic for over 1000 n mi. The Gulf Stream is believed to extend to the bottom throughout much of its length. With surface current speeds of 3-5 knots, it forms a dynamic boundary between the Slope Water and the warmer, more saline Sargasso Sea.

Change in the sound velocity profile across the front is illustrated in Fig. 4. Mean profiles for Slope, Gulf Stream, and Sargasso Sea Water for May have been superimposed to demonstrate the change in near-surface sound velocity. A difference in surface sound velocity of 30 m s^{-1} (100 ft s^{-1}), as shown here, can be critical in determining whether there is sufficient velocity excess to allow convergence zone propagation. The profiles also indicate deepening of the DSC from 500 m in Slope Water to 1200 m in Sargasso Water. For a shallow sound source in Slope Water, this will have the effect of concentrating sound into the DSC as it crosses the Gulf Stream and propagating it for hundreds of miles through the Sargasso Sea (Gemmill, 1974).

SLD can have a significant effect on direct path and surface channel transmission. Season variability of this parameter in the Gulf Stream region is illustrated in Fig. 5 by April and September temperature sections across the Stream. During winter and spring surface cooling and convective mixing create a very deep layer in the Sargasso Sea and changes in SLD across the Gulf Stream on the order of 500 ft are common. At the end of summer, however, formation of a seasonal thermocline in the Sargasso can completely eliminate the change in SLD.

b) <u>The Slope Front</u> is a moderate ocean front which separates Slope Water from colder Shelf Water adjacent to the coast. It follows the 100 fathom depth contour quite closely and runs approximately parallel to the Gulf Stream. Because of this relatively shallow depth the Slope Front extends to the bottom

throughout its length, but during late summer it does not always exist at the surface. This is shown in the two sections in Fig. 5 where the Slope Front can be seen at the far left at the edge of the Continental Shelf. In April the Slope Front is fully developed, exhibiting a surface temperature gradient of 8°C (14°F) in only about 30 n mi; this results in a sound velocity difference of about 100 ft s^{-1}. During this time of year SLD can change by 250 ft across the southern boundary of the front. In September, however, development of the seasonal thermocline has destroyed the front at the surface and reduced it to a 4°C (7°F) gradient near the bottom. Like the Gulf Stream, the Slope Front meanders about its mean position but can always be found within a well defined envelope (Fig. 6).

c) The Sargasso Sea Front is a prime example of a weak front. It exists only for about 4 months in late winter and spring when it may extend along 29°N between the Bahamas and Bermuda. Fig. 7 shows its position in late May 1965 when it was surveyed by aircraft using infrared thermometry. It is created when opposing wind systems push cold surface water southward toward slightly warmer water which is moving northward. Maximum temperature difference across the Sargasso Sea Front is only about 2°C (3.6°F) and this gradient extends to a depth of 300-700 ft. There is no appreciable change in SLD on opposite sides of the front although layer depths may be reduced inside its boundaries.

FUTURE WORK

One of the goals of the Environmental Analysis Branch is to gain a more complete understanding of the acoustic effect of ocean fronts and to apply this knowledge to ASW tactics. Much has been learned from experiments in the Gulf Stream and from improved theoretical computer models. Experiments can now be refined to answer questions which still remain. These tests will be conducted in conjunction with a program to survey strategic fronts around the world. In addition to planned ship and aircraft surveys, ships of opportunity will be requested to collect data in regions of known frontal activity. Newly gathered data, together with past studies of fronts, will be used to compile an atlas of ocean fronts on a world-wide scale. The atlas will contain the positions of fronts and the effect of each on sonar systems.

Infrared satellite imagery will be an important input to the frontal program. Since 1973 daily photos from the NOAA satellite series have been used to produce weekly charts showing positions of Gulf Stream, Slope Front, and Gulf Stream eddies. It is planned to compile similar charts for major fronts such as the Kuroshio and Oyashio east of Japan in order to study their change with time. Satellite capabilities should increase greatly with the launching of SEASAT in 1978. This new satellite will have active radar, passive microwave and infrared sensors which will enable it to measure wind speed and direction, wave height, tides, currents, and sea surface temperature during day and night. It will be able to make observations through moderate cloud cover and during winds up to hurricane force.

Data collected during the program will also be used to create statistical models of ocean fronts. With these models it will be possible to forecast the impact of selected fronts on fleet operations and exercises.

REFERENCES

Cheney, R.E. and P.L. Richardson (1975) Distribution of Gulf Stream rings in the northwestern Sargasso Sea. MODE Hot Line News, No. 79.

Cheney, R.E. (1976) A census of rings in the Gulf Stream system. U.S. Naval Oceanographic Office, Tech. Note 3700-44-76.

Cheney, R.E. and P.L. Richardson (1976) Observed decay of a cyclonic Gulf Stream ring. Deep-Sea Research, 23, 143-155.

Cromwell, T., and J.L. Reid (1956) A study of oceanic fronts, Tellus, 1, 94-101.

Gemmill, W.H. and E. Khedouri (1974) A note on sound ray tracing through a Gulf Stream eddy in the Sargasso Sea. U.S. Naval Oceanographic Office, Tech. Note 6150-21-74.

Gemmill, W.H. (1974) A note on sound ray tracing across the Gulf Stream. U.S. Naval Oceanographic Office, Tech. Note 6150-27-74.

Hansen, D.V. (1970) Gulf Stream meanders between Cape Hatteras and the Grand Banks. Deep-Sea Research, 17, 495-511.

Ingham, M.C. (1976) Variations in the Shelf Water Front off the Atlantic coast between Cape Hatteras and Georges Bank. National Marine Fisheries Service, Marine Resources Monitoring, Assessment, and Prediction Program (MARMAP), Contribution No. 104.

James, R.W. (1972) Criticality of ocean fronts to ASW operations. U.S. Naval Oceanographic Office, Tech. Note 7700-3-72.

Khedouri, E. and P. Gaborski (1976) Acoustic ray tracing and 3-D representation of propagation loss in the Gulf Stream region. U.S. Naval Oceanographic Office, Tech. Note 3700-55-79.

Laevastu, T., Wolff, P., and E. LaFond (1971) Effects of ocean fronts on sound propagation and possible implications for ASW tactics. Naval Undersea Research and Development Center, Tech. Pub. 226.

Levenson, C. and R.A. Doblar (1976) Long-range propagation through the Gulf Stream. Journal of the Acoustical Society of America, 59, 1134-1141.

Levine, E.R. and W.B. White (1972) Thermal frontal zones in the eastern Mediterranean Sea. Journal of Geophysical Research, 77, 1081-1086.

Vastano, A.C. and G.E. Owens (1973) On the acoustic characteristics of a Gulf Stream cyclonic ring. Journal of Physical Oceanography, 3, 470-478.

Voorhis, A.D. and J.B. Hersey (1964) Oceanic thermal fronts in the Sargasso Sea. Journal of Geophysical Research, 69, 3809-3814.

APPENDIX A

Names of ocean fronts shown in Fig. 1

Atlantic Ocean Fronts

1 Loop Current (Gulf of Mexico)
2 Gulf Stream
3 North Atlantic Current (North Polar Front)
4 Slope Front
5 Sargasso Sea Front
6 Subtropical Convergence
7 Iceland-Faeroe Islands Front
8 Denmark Strait Front
9 East Greenland Polar Front
10 Greenland-Norwegian Sea Front
11 Bear Island Front
12 Northwest African Upwelling
13 Gulf of Guinea Front
14 Guiana Current
15 Benguela Upwelling
16 Subtropical Convergence
17 Antarctic Convergence (South Polar Front)
18 Antarctic Divergence

Mediterranean Sea Fronts

19 Huelva Front
20 Alboran Sea Front
21 Maltese Front
22 Ionian Sea Front
23 Levantine Basin Front

Indian Ocean Fronts

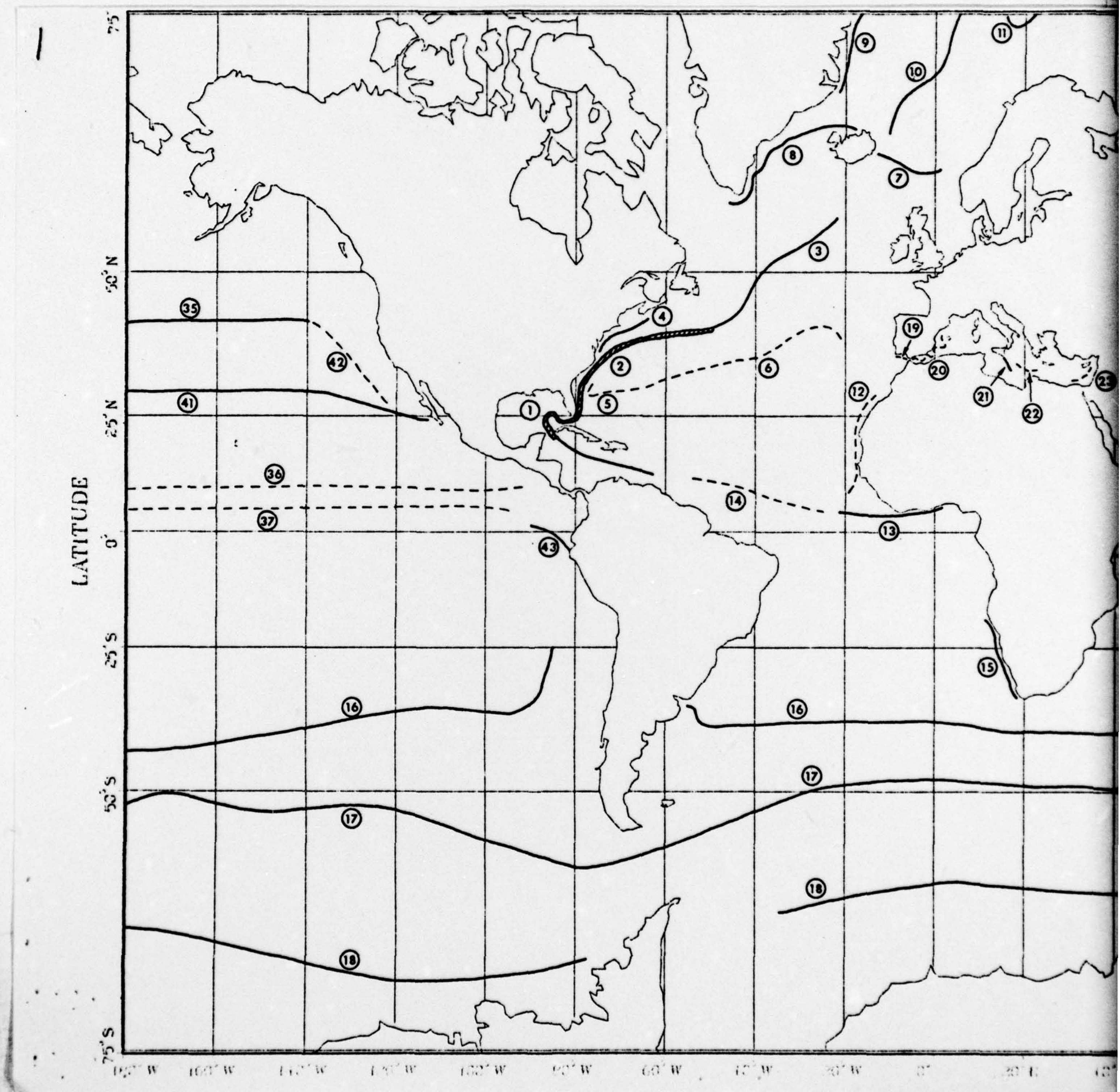
24 Somali Upwelling
25 Arabian Upwelling
26 Indian Ocean Salinity Front
27 Equatorial Countercurrent Fronts
28 West Australian Front

Pacific Ocean Fronts

29 Kuroshio Front
30 Yellow Sea Warm Current
31 Korean Coastal Front
32 Tsushima Current
33 Oyashio Front
34 Kuril Front
35 Subarctic Front
36 North Doldrum Salinity Front
37 South Doldrum Salinity Front
38 Tropical Convergence
39 Mid Tasman Convergence

40 Australian Subarctic Front
41 Subtropical Front
42 California Front
43 East Pacific Equatorial Front

Fig. 1 - The world-wide distribution of ocean fronts. Numbers correspond to generally accepted names in Table 1. Fronts are classified as either strong, moderate, or weak according to the criteria in Table 2.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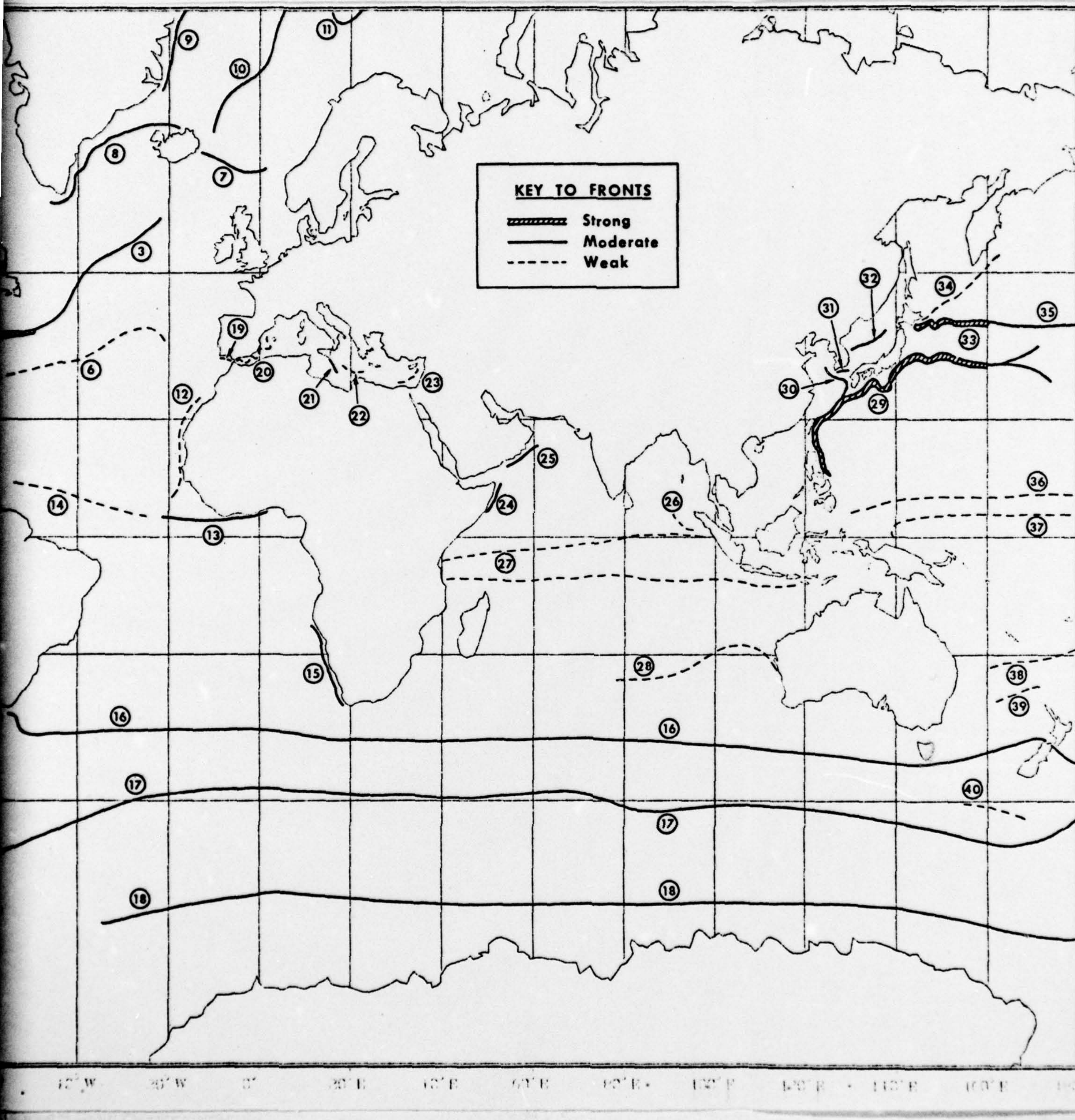
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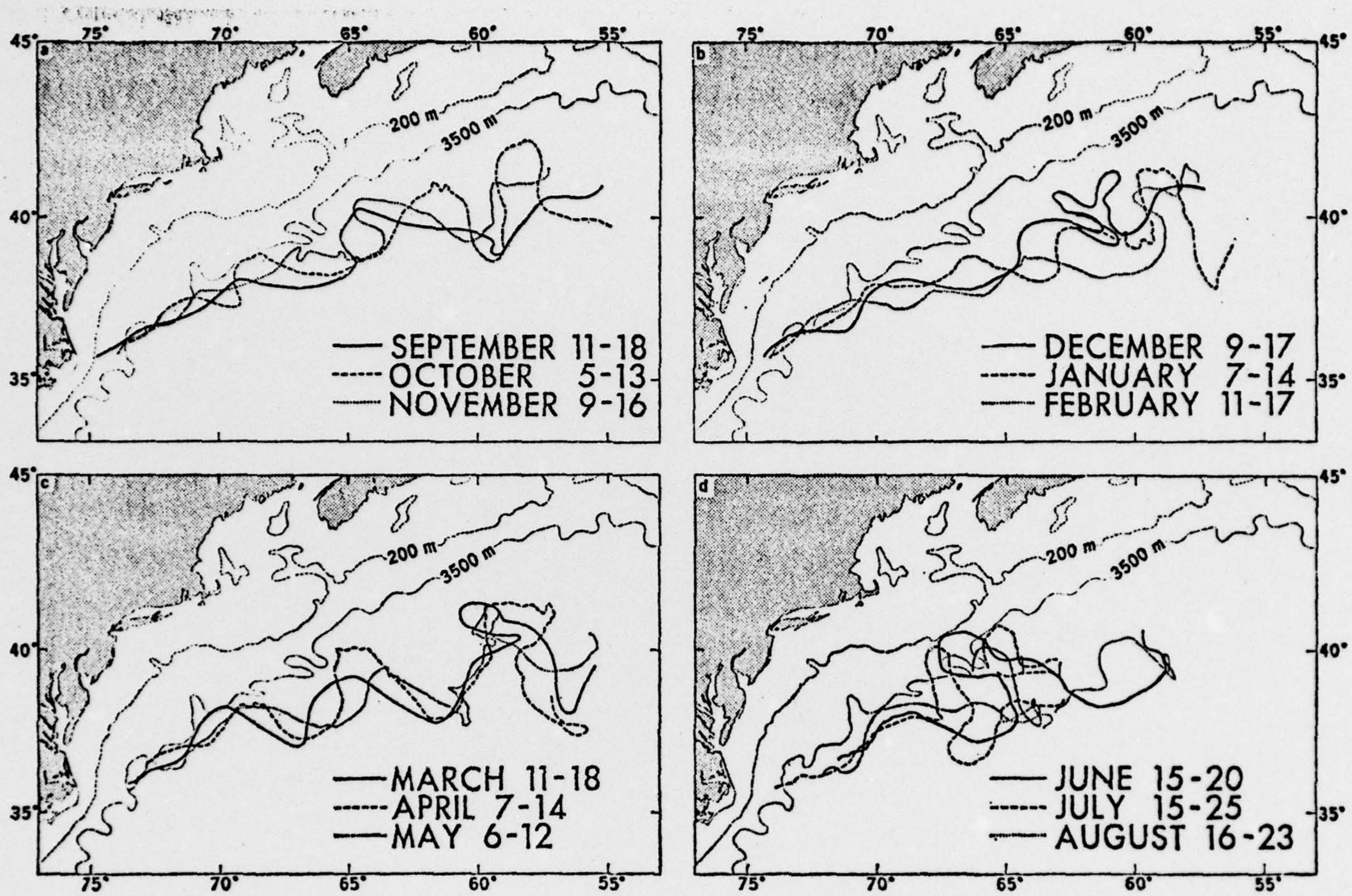


Fig. 2 - Position of the Gulf Stream (15°C isotherm at 200 m) observed September, 1965 - August, 1966. Meandering may cause the Stream to be located 100 nmi north or south of its mean position. (From Hansen, 1970)

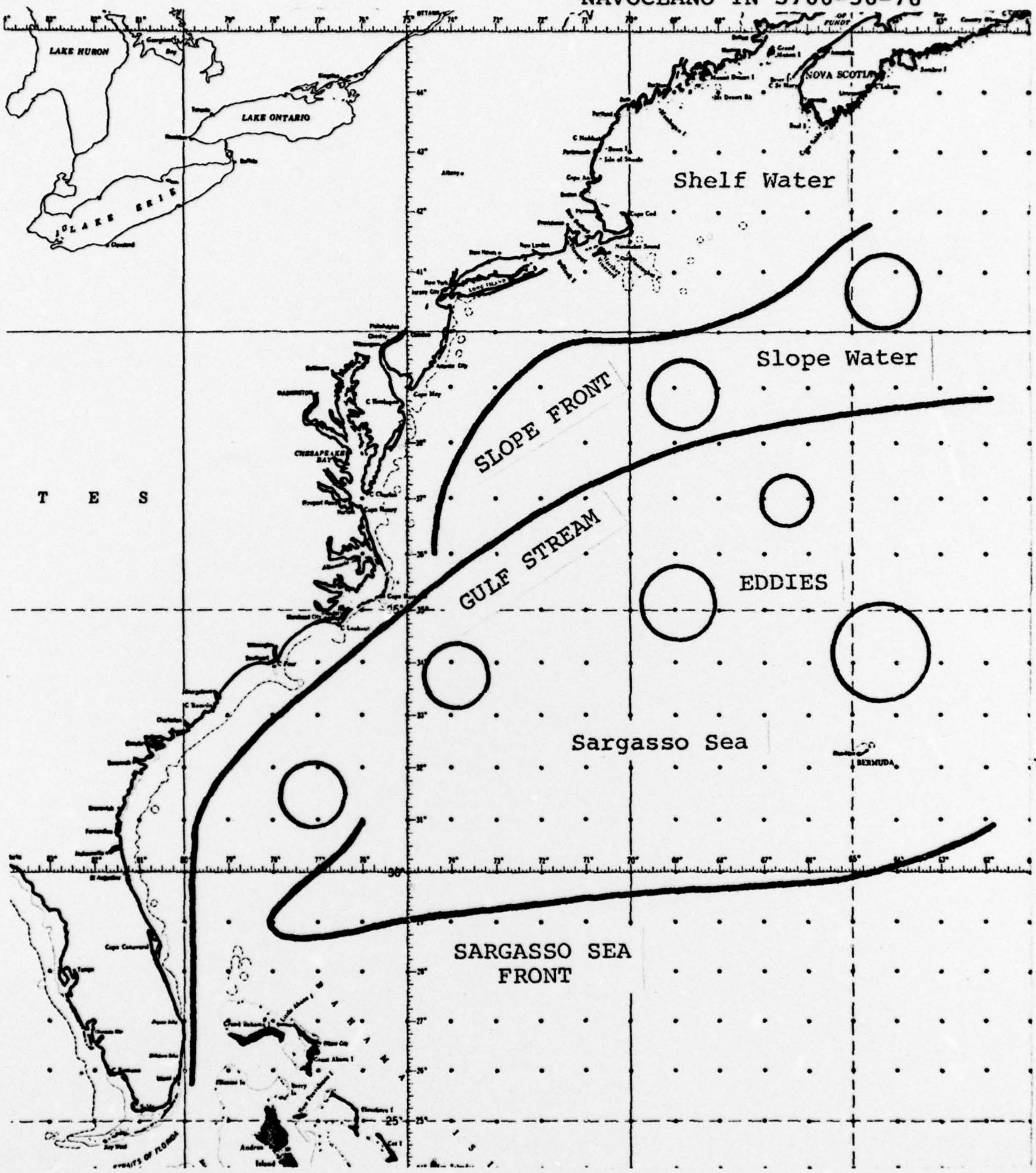


Fig. 3 - Mean positions of three fronts in the western North Atlantic. The Gulf Stream is a strong front between Slope Water and the Sargasso Sea. The Slope Front separates Shelf and Slope Water and is a moderate front. The Sargasso Sea Front is weak and occurs within a single water mass. A representative number of warm and cold eddies is included.

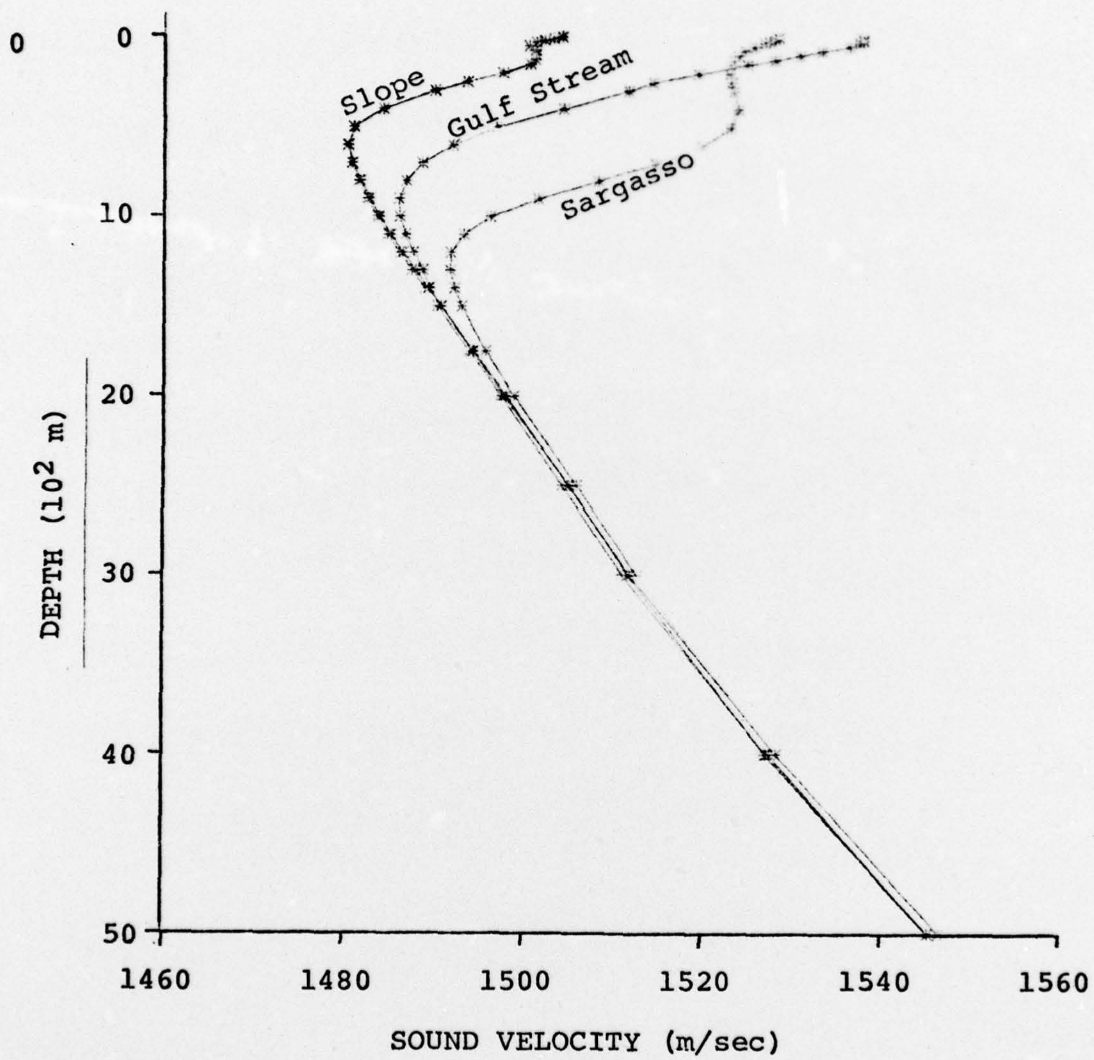
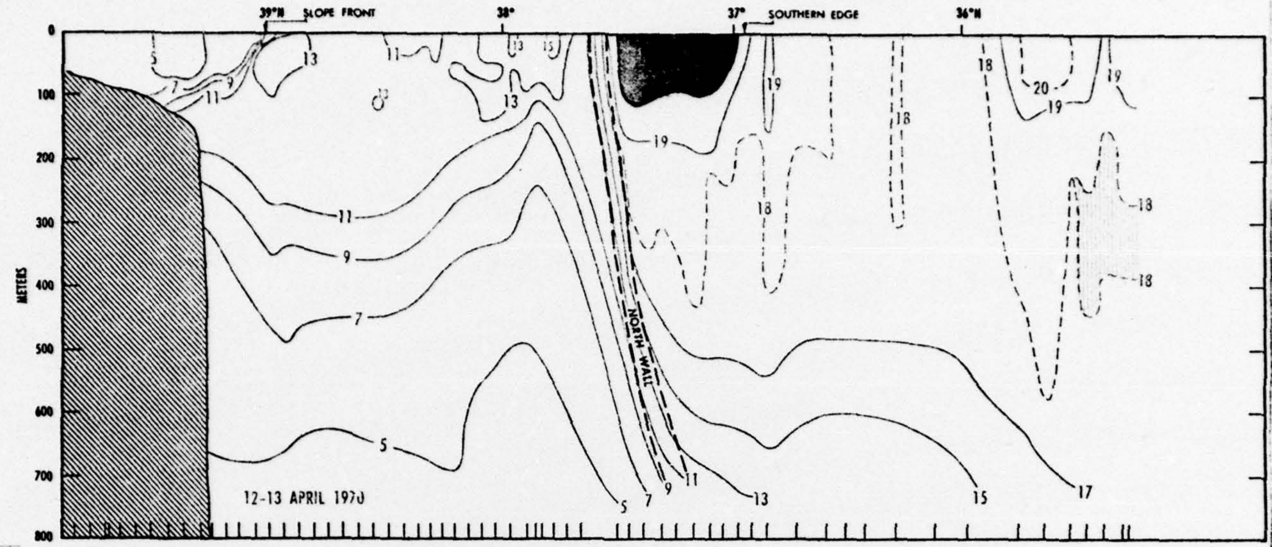


Fig. 4 - Sound velocity profiles in Slope Water, Gulf Stream, and Sargasso Sea Water during May. Surface sound velocity increases approximately 30 m s^{-1} (100 ft s^{-1}) across the Gulf Stream and DSC deepens about 700 m (2300 ft).



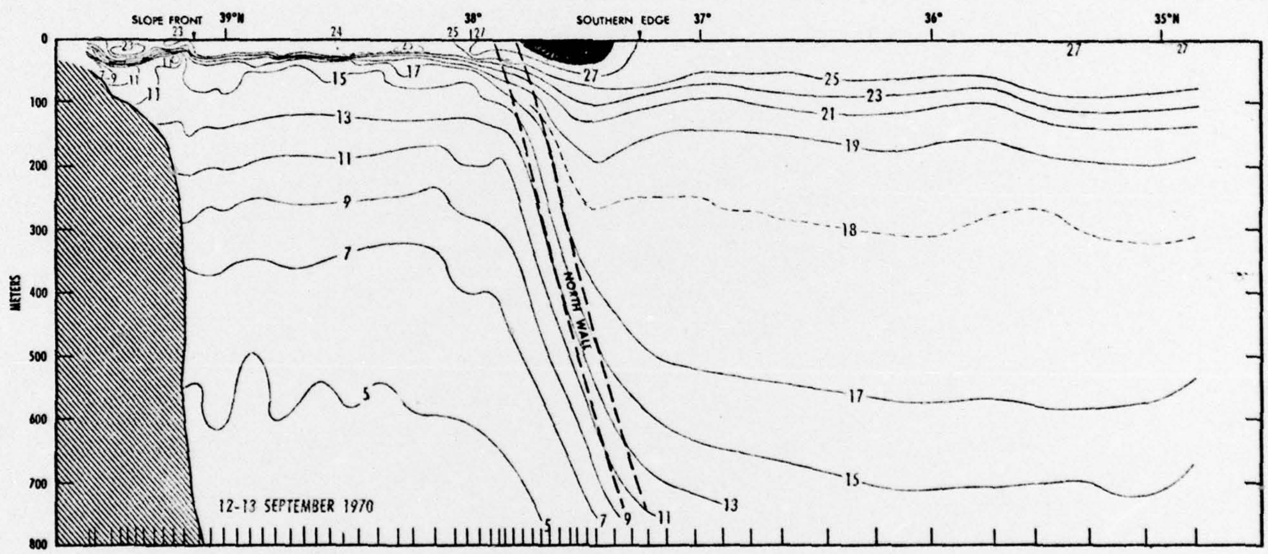


Fig. 5 - Temperature sections across the Slope Front and Gulf Stream along a line from New York to Bermuda. 760 m SXBT locations are indicated by tick marks; temperatures are °C. The April section is characterized by a deep mixed layer created by winter cooling while the September section shows a fully developed seasonal thermocline caused by surface heating during summer.

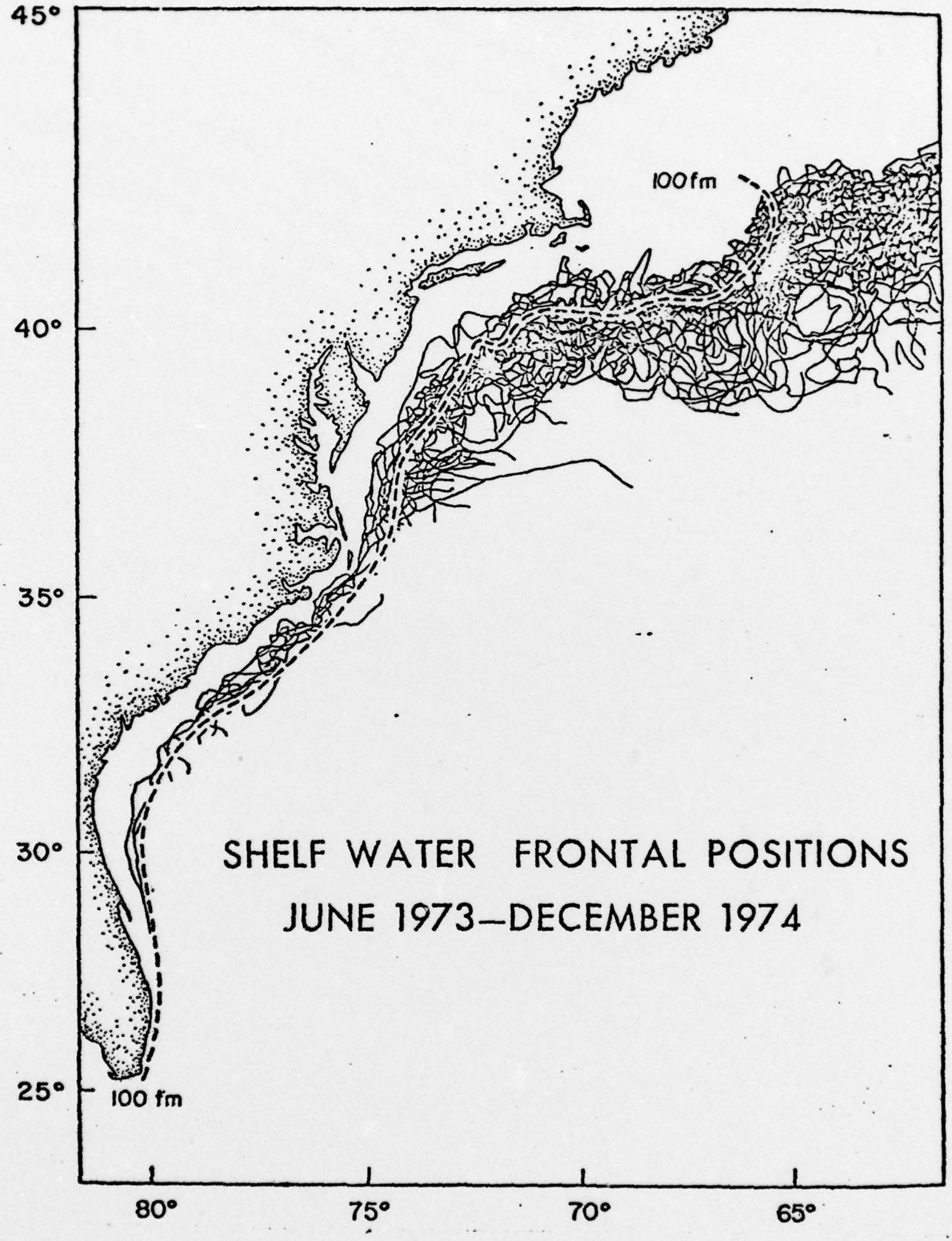


Fig. 6 - Composite plot of positions of the Slope Front as observed by satellite during June 1973 - December 1974. Heavy dashed line indicates location of edge of continental shelf. (From Ingham, 1976)